



United States Air Force Research Laboratory

EVALUATION OF THE JOINT SERVICE MUSTANG ANTI-G SUIT

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SYMBOLS, ABBREVIATIONS, AND ACRONYMS

AFRL	Air Force Research Laboratory
CE	COMBAT EDGE (Combined Advanced Technology Enhanced Design G Ensemble)
CSU-13B/P	Standard Aircrew 5 bladder Anti-G Suit
GOR	Gradual Onset Run
HEPG	Aircrew Protect Branch
JSMAGS	Joint Service Mustang Anti-G Suit
ROR	Rapid Onset Run
SACM	Simulated Aerial Combat Maneuver

1.0 SUMMARY: Comparison study of the Joint Service Mustang Anti-G Suit to that of the standard CSU-13B/P Anti-G Suit

Purpose: In response to a request from 311th Human Systems Wing (311 HSW), the Air Force Research Laboratory Aircrew Performance and Protection Branch (AFRL/HEPG) conducted an initial evaluation of the Joint Service Mustang Anti-G Suit (JSMAGS) produced by Mustang Survival, Inc. Performance of the JSMAGS was compared to that of the CSU-13B/P anti-G suit. This test was designed to provide the Human Systems Wing (HSW) program an initial evaluation of the performance of Mustang model MSF 890 Joint Service Mustang Anti-G Suit (JSMAGS) and provided data for a comparative analysis of the current CSU13B/P anti-G trouser.

Method: Four subjects completed centrifuge trials up to +9 Gz using positive pressure breathing provided by the Combined Advanced Technology Enhanced Design G Ensemble (COMBAT EDGE) system in combination with each of the two anti-G suits. Subjects completed centrifuge exposures up to +9 Gz using pressure breathing for G (PBG) at 60 mm Hg pressure with a counter-pressure vest while comparing the effects of the two separate anti-G suits, the JSMAGS and the CSU-13B/P. The tests were conducted within the limits established by a test plan previously approved by the Brooks Institute Review Board. The constraints of that test plan did not permit a determination of the G-endurance afforded by JSMAGS compared to that of the CSU-13B/P.

Results: The results of the trials were as follows:

1. No apparent differences in both heart rate and discomfort during the gradual onset run (GOR) and the straining portion of the GOR were found between the COMBAT EDGE(CE)/CSU-13B/P and CE/JSMAGS.
2. No apparent differences were found for discomfort, and effort level throughout the rapid onset runs (ROR) between the two conditions, except for heart rate, which was lower with the Mustang (JSMAGS) equipment.
3. No apparent differences were found between the two conditions during the maximal four 9-G peaks of the simulated aerial combat maneuvers (SACM), except for heart rate, which was lower with the Mustang G-suit (JSMAGS) compared to that of the CE/CSU-13B/P.
4. The results from the evaluation questionnaire regarding ease of donning and doffing of both G-suits, connecting and disconnecting the G-hose, and compatibility with other equipment revealed no apparent differences between the two equipment conditions
5. Results of the evaluation questionnaire regarding overall fit and performance were slightly better with the Mustang G-suit (JSMAGS), while comfort was rated just slightly higher for the CSU-13B/P.
6. With regard to the overall G-protection, the Mustang (JSMAGS) scored slightly better for both G-protection and reduced fatigue.

Discussion: While the small number of subjects in this “quick-look” assessment did not permit any definitive statistics, these initial test results indicate that JSMAGS provides G-protection that is comparable to that provided by the CSU-13B/P and, as indicated by the heart rate data, may require less physical effort to provide that level of protection. Had the test plan limits permitted a longer SACM exposure, endurance values for JSMAGS may have been better due to a decreased physical effort requirement.

2.0 BACKGROUND: The JSMAGS has been developed as a result of knowledge acquired during the involvement in all of the current advanced technology anti-G programs in North America during the past ten years. These programs include the Canadian STING ensemble, F-22 ensemble, COMBAT EDGE, ATAGS and the US Navy MSF 840. This involvement provided the opportunity to gain first hand knowledge of both the successes and shortcomings of these programs, which in turn allowed addressing them in the development of the MSF 890. JSMAGS has been designed to accommodate a full range of legacy aircraft as well as the F-22 and potentially the JSF aircraft.

Issues addressed include but are not limited to: manufacturability, life cycle costs, maintainability, enhanced performance and comfort. The objective of the design of this product was to provide the enhanced G performance required for current and future combat aircraft, while addressing the concerns noted during the development of previous full coverage garments.

The JSMAGS is a full circumferential coverage anti-G trouser developed to provide necessary G-protection.

Impact: This test will give information about performance and comfort of JSMAGS during increased G-loads and a comparison to CSU 13B/P AGS ensemble.

3.0 METHODS:

Four male volunteer subjects started and completed the study. All were recruited acceleration subject panel members. The subject's ages were 28 - 42 years (mean 36), weight 145 - 205 lbs. (mean 177) and height 65 - 71 inches (mean 68).

Subjects' activity, food and fluid intake the day prior to each test was *ad libitum*, except for alcohol, which was not allowed.

Centrifuge Seat Back Angle: 13 degree tilt back (F-15 configuration)

Centrifuge Trials: Each subject completed two trials – one using the equipment configuration below in combination with JSMAGS; and a second using the equipment with the CSU-13B/P

Subjects' Equipment Configuration:

- CWU-27/P aircrew coverall
- Modified HGU-55/P helmet
- MBU-20/P oxygen mask
- CSU-17/P counter-pressure vest
- CRU-94/P integrated terminal block
- PCU-15A/P or 16A/P Parachute Harness
- JSAMGS or CSU-13B/P

Breathing Regulator: CRU-93/A

Experimental Plan:

a. Equipment and facilities:

Tests were conducted in the AFRL/HEP human centrifuge. The centrifuge cab was configured to supply anti-G suit pressure and PBG (pressure breathing for G) according to the standard COMBAT EDGE schedule (currently used in F-15s, F-16s, and F/A-18s). The AFRL/HEP Cockpit and Equipment Integration Laboratory (CEIL) was used for subject test preparation. AFRL/HEP collected ECG for medical monitoring using its standard centrifuge system.

A 13° seat back angle was used during all testing.

JSMAGS and CSU 13B/P ensembles were used together with A CRU-93/P regulator and CRU-94/P Connector

b. Objective Measurements:

- 1) Standard sternal and biaxillary ECG electrodes
- 2) Anti-G suit pressure

c. Subjective Measurements:

- 1) Light loss
- 2) Comfort, fatigue, and workload assessments during the centrifuge insertion

d. Requirements for Human Volunteers:

- 1) Four volunteer subjects were evaluated. All volunteers were members of the HEP acceleration subject panel. All volunteers were trained in the use of PBG and have demonstrated G tolerance exposures to +9 Gz for 15 seconds.
- 2) Age: 22 - 45 years.
- 3) Gender: only male subjects were used due to availability.
- 4) Subject's activity, food and fluid intake the day prior to each test were *ad libitum*.

e. Duration of Study:

- 1) Subjects will initially be asked to report to the Cockpit and Equipment Integration Laboratory for fitting of the garments.
- 2) Each subject will be required to participate in two approximately one-hour exposures on two different days of the week.

f. Test Procedures:

- 1) Prior to the first centrifuge exposure, the subject reported to the Cockpit and Equipment Integration Laboratory for fitting of the garments.
- 2) Standard sternal and biaxillary ECG electrodes were attached. The subjects dressed and were fitted with the anti-G ensemble.
- 3) The subjects proceeded to the centrifuge (F-15 seat configuration) and underwent +Gz exposures. During these exposures, subjects performed the anti-G straining maneuvers (AGSM) as necessary. The following sequence of G-profiles were used to evaluate the different ensembles. These profiles include both standard and simulated mission scenario centrifuge exposures.

I. Gradual onset (0.1 G/s) run (GOR) to +9 Gz. Subjects performed an anti-G straining maneuver (AGSM) as necessary to maintain vision up to the maximum +9 Gz. End point criteria were subject reported 100% loss of peripheral vision or 50% loss of central vision as determined by peripheral lights at a 50° angle from centerline and a central light.

II. After a minimum 2 min rest period, a series of rapid onset (6 G/s) exposures to + 5 Gz for 15 seconds, +7 Gz for 15 s, +8 Gz for 15 s and +9 Gz for 15 s occurred. The subjects performed an AGSM as necessary to complete the plateau. They were instructed to terminate the plateau if they reached vision end point criteria. The subjects had a 2 minute rest period between each exposure.

III. A 5 min rest follows the completion of the first set of GOR and three ROR exposures. This is followed by a simulated aerial combat maneuver (5-9 G SACM) profile (70 s duration) with alternating 10 s plateaus at +5 and +9 Gz with 6 G/s transitions and with a maximum of 3 peaks at +9 Gz.

g. Measurements Recorded:

- 1) Level or duration of G exposures completed
- 2) Peak heart rate for each centrifuge run
- 3) Subjects' comfort, fatigue, and workload assessments for each centrifuge run using the following scale:

0	Nothing at all
0.5	Very, very weak (just noticeable)
1	Very weak
2	Weak (light)
3	Moderate
4	Somewhat strong
5	Strong
6	
7	Very strong
8	
9	
10	Very, very strong (almost max)
11	Maximal

h. Statistical Analysis: N/A

4.0 RESULTS:

The G-level and heart rate reached, and discomfort level reported, during the relaxed portion of the gradual onset run (GOR) and the straining part of the GOR can be seen in Table 1. For all tables, CE-Std refers to the COMBAT EDGE (CE)/CSU-13B/P combination and Mustang refers to the CE/JSMAGS combination. No apparent differences were found between the two G-suits.

Table 1. Final G-levels, discomfort and heart rate (HR) during the relaxed and straining portions of the gradual onset runs (GOR) with Mustang (CE-JSMAGS) and CE-Std (CE/ CSU-13B/P).

Subject (relaxed)	GOR	GOR	GOR	GOR	GOR	GOR	GOR	GOR
	(relaxed)	(relaxed)	(straining)	(straining)	(straining)	(straining)	(straining)	(straining)
	G	G	G	G	Discomfort	Discomfort	HR	HR
	CE-Std	Mustang	CE-Std	Mustang	CE-Std	Mustang	CE-Std	Mustang
1	9.0	8.3	9.0	9.0	1	0.5	150	140
2	7.6	7.5	9.0	9.0	0	2	145	155
3	9.0	9	9.0	9.0	2	1	150	145
4	6.0	6.7	9.0	9.0	2	3	130	135
Mean	7.9	7.9	9.0	9.0	1.3	1.6	144	144
SD	1.4	1.0	0.0	0.0	1.0	1.1	9	9

The duration, discomfort, heart rate, and effort level during rapid onset runs (ROR) can be seen in Table 2. No differences were found between the two conditions, except for heart rate, which was lower with the Mustang equipment.

Table 2. The duration of the rapid onset runs (ROR), and the discomfort, heart rate and effort level during the RORs. The duration represents the cumulative number of seconds each subject completed during the 5, 7, 8, and 9G 15-second plateaus; thus, the maximum possible duration is 60 seconds.

Subject	ROR with straining maneuver							
	Duration	Duration	Discomfort	Discomfort	HR	HR	Effort	Effort
	CE-Std	Mustang	CE-Std	Mustang	CE-Std	Mustang	CE-Std	Mustang
1	60	60	0	0	160	125	1	0.5
2	60	60	2	3	165	155	6	6
3	60	60	2	1	155	157	2	1
4	54	60	0.5	1	157	145	3	2
Mean	59	60	1.1	1.3	159	146	3.0	2.4
SD	3	0	1.0	1.3	4	15	2.2	2.5

The duration during the maximal four 9-G peaks of the simulated aerial combat maneuver (SACM), and the discomfort, heart rate and effort level with the CE/Std and Mustang equipment can be seen in Table 3. No apparent differences were found between the two conditions, except for heart rate, which was lower with the Mustang G-suit.

Table 3. The duration, discomfort, heart rate and effort level associated with the simulated aerial combat maneuver (SACM). Maximum possible time for the SACM is 65 seconds.

Subject	SACM									
	Duration		Discomfort		HR		Effort			
	CE-Std	Mustang	CE-Std	Mustang	CE-Std	Mustang	CE-Std	Mustang		
1	65	65	1	0.5	140	125	2	3		
2	65	65	2	3	170	155	4	6		
3	65	65	3	3	170	165	3	2		
4	65	65	2	3	165	142	5	3		
Mean	65	65	2.0	2.4	161	147	3.5	3.5		
SD	0	0	0.8	1.3	14	17	1.3	1.7		

The results from a questionnaire regarding ease of donning and doffing of the G-suit, connecting and disconnecting the G-hose, and compatibility with other equipment are shown in Table 4. The scale units were 1=Very Unsatisfactory, 2=Unsatisfactory, 3= Marginally Unsatisfactory, 4= Marginally Satisfactory, 5=Satisfactory, 6=Very Satisfactory. No apparent differences were found between the two equipment conditions.

Table 4. The result from a questionnaire regarding ease of donning and doffing the G-suit, connecting and disconnecting the G-hose, and compatibility with other equipment. The scale ranges from 1=Very Unsatisfactory to 6=Very Satisfactory.

Subject	Ease donning/doffing		Connecting/disconnecting		Compatibility with other equipment	
	G-suit		G-hose			
	CE-Std	Mustang	CE-Std	Mustang	CE-Std	Mustang
1	6	6	5	5	6	5
2	5	5	5	4	3	5
3	6	5	6	6	6	6
4	5	5	6	6	5	6
Mean	5.5	5.3	5.5	5.3	5.0	5.5

Table 5 shows the results from a questionnaire regarding overall fit, performance, and comfort of the G-suits. Fit and performance were slightly better with the Mustang G-suit, while comfort was rated just slightly higher for the CSU-13B/P.

Table 5. The results from a questionnaire regarding overall fit, performance, and comfort of the G-suits. The scale ranges from 1 = Very Unsatisfactory to 6 = Very Satisfactory.

Subject	Overall fit of G-suit		Overall performance of G-suit		Overall comfort of G-suit	
	CE-Std	Mustang	CE-Std	Mustang	CE-Std	Mustang
1	5	6	6	6	6	6
2	3	5	5	5	4	5
3	6	6	6	6	6	5
4	6	6	5	6	6	5
Mean	5.0	5.8	5.5	5.8	5.5	5.3

Table 6 shows the subjects' rating of the two G-suit conditions with regard to overall G-protection and the least amount of fatigue encountered during the G-exposures. The ratings were based on a scale of 1 = best, 1.5 = no difference, and 2 = not the best. Mustang scored slightly better for both G-protection and reduced fatigue.

Table 6. Subjective rating of the two equipment conditions with regard to overall G-protection and least amount of fatigue during the G exposures: 1 = best, 1.5 = equal, and 2 = not the best.

Subject	Overall		<u>Fatigue</u>	
	G-protection			
	CE-Std	Mustang	CE-Std	Mustang
1	2	1	2	1
2	2	1	2	1
3	1.5	1.5	1.5	1.5
4	2	1	2	1
Mean	1.9	1.1	1.9	1.1

5.0 DISCUSSION:

While the small number of subjects in this quick-look effort did not permit any definitive statistics, these initial test results indicate that JSMAGS provides G-protection that is comparable to that provided by the CSU-13B/P and, as indicated by the heart rate data, may require less physical effort to provide that level of protection. Had the test plan limits permitted a longer SACM exposure, endurance values for JSMAGS may have been better due to a decreased physical effort requirement.